Structural Ceramics for Advanced Turbomachinery Applications

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TABLE 7.—*Commercial and NASA benefits.*

Issue	Aspect	Benefit
Scientific and Technical Merit	• Turbopump With Ceramic Turbine Wheel • Production-Ready Gelcasting Technique • Viable Braze Attachment	• Reduced Weight, Increased Temperature • Commercially Viable Ceramic Components • Increased Torque Capacity
Commerical and NASA Applications	• Improved-Performance, Low-Weight Turbopumps • Turbochargers for Automotive and Off-Road • Turbogenerators for Hybrid Electric Vehicles	• Increased Payload Launchers • Domestic Production of Turbochargers • Improved-Performance Hybrid Electric Vehicles
Benefits	• Reduced Launch Costs	• Increased Launch System Affordability

The team of Allied Signal Aerospace Equipment Systems, Allied Signal Ceramic Components, Allied Signal Research and Technology, Lockheed Martin Manned Space Systems, and MSFC has entered into a cooperative agreement under the NASA Aerospace Industry Technology Program to develop and demonstrate dual-use ceramic turbine wheel technology applicable to turbopumps, turbochargers, and turbogenerators for hybrid electric vehicles.

The primary goal of this project is to develop a reduced-cost ceramic component manufacturing process ready for commercialization. An additional thrust is the development and demonstration of ceramic turbine wheels in a turbopump application, which will benefit launch vehicles due to improved performance and reduced weight. See table 7 for other benefits.

Commercialization of ceramic turbine wheel technology for advanced turbomachinery applications requires significant reduction in production costs. The team will develop and demonstrate low-cost, high-yield ceramic manufacturing processes. The objective will be met by accomplishing three technology advances: (1) developing gelcasting as a low-cost, high-yield ceramic forming process; (2) developing brazing as a high-load capacity, low-cost ceramic-to-metal attachment; and (3) demonstrating ceramic turbine wheels in a cryogenic turbopump. Technical objectives are shown in table 8.

The manufacturing process development will build on experience with gelcasting; the new ceramic-to-metal attachment will build on current brazing experience. The technology will be demonstrated by producing turbine wheels and testing them in an Aerospace Equipment Systems-developed cryogenic turbopump. Tests will be conducted using the turbopump and a NASA gas generator adapted for oxygen-rich operation, while also using steam-generating equipment being developed by Lockheed for hybrid rocket applications. Two turbine wheel configurations will be tested: an axial impulse turbine, applicable to turbopumps and turboalternators, and a radial turbine, applicable to turbochargers and turbogenerators for hybrid electric vehicles.

Aerospace Equipment Systems is designing the turbine wheels and components needed to adapt the turbine wheels to the existing turbopump, as MSFC designs the hardware required to adapt an existing thrust chamber for use as an oxygen-rich gas generator. These two team members will conduct tests of the turbopump jointly. Ceramic Components is developing the gelcasting technique, conducting material characterization tests, and will produce the turbine wheels. While Allied Signal Research and Technology will develop the ceramic-to-metal brazing technique and transfer this technology to Ceramic Components and Aerospace Equipment Systems, Lockheed Martin will provide hybrid rocket motor-based steam-generation equipment used to test the turbopump.
without interlayer materials to

TABLE 8.—*Technical objectives.*

Objective	Approach	Benefit
Develop a Low-Cost, High-Yield Ceramic Forming Process	• Fabricate Axial and Radial Turbine Wheels	• Opens New Automotive Markets for Ceramic Components
Develop a High-Torque-Capacity Ceramic/Metal Attachment	• Braze Wheels to Metal Shafts	• Enables Application of Ceramic Turbines to Turbopumps
Build and Test Two Configurations of Ceramic Turbine Wheels	• Adapt Ceramic Wheels to Existing Turbopump • Test Turbopump With Steam Drive • Test Turbopump With Hot-Gas Drive	• Demonstates Potential for Improved-Performance, Reduced-Weight Turbopumps

The turbopump will undergo mechanical integrity verification tests, first with the steam generator in ambient conditions, and then tests under cryogenic conditions. Oxygen-rich, 1,000 °F gas will be used to drive the turbine while pumping liquid oxygen. The hot-gas/liquid-oxygen testing will demonstrate the ceramic turbine wheel/shaft attachment system capability with high thermal gradients, and will verify the capability of the ceramic turbine wheel material. Table 9 lists testing approaches and objectives.

Since the program kickoff on April 4, 1995, Aerospace Equipment Systems has completed conceptual design layouts of both axial and radial turbopump configurations and has begun detailed design and analysis. The radial turbine aerodynamic design is being performed in conjunction with an automotive turbogenerator program currently underway. Preliminary drawings of the turbine wheels have been released to allow Ceramic Components to fabricate tooling to be used for process development.

Ceramic Components has begun process optimization; work to date has focused on design of experiments for optimization of the binder burnout and densification phases of the gelcasting process. The company is reviewing past history of mold designs for gelcasting research programs for optimization under the Aerospace Industry Technology Program. Design and procurement of development molds have begun, and the company has planned a program to cast existing turbine wheel designs to evaluate dimensional control and repeatability.

Allied Signal Research and Technology has conducted a number of tests of brazed shaft attachments using a variety of sizes, materials, and geometric configurations. Full torque strength has been achieved in a full sizer joint using a simple geometry consisting of a Si_3N_4 (silicon nitride) stub shaft brazed into a Kovar cup. Braze materials and techniques have been refined, improving repeatability. Near-term work will consist of brazing to preferred turbopump shaft materials using butt joints, with and

TABLE 9.—*Test approaches and objectives.*

Test	Approach	Purpose and Results
Turbopump Reference Fluid Tests	• Full-Pressure Air Tests • Full Flow-Rate Water Tests • Testing at AES Facilities	• Verify Hydrodynamic Performance • Verify Mechanical Integrity
Hybrid/Steam Turbo-pump Drive System	• Steam Generator Drive System • Pump Tested in Water	• Verify Ceramic/Metal Brazed-Joint Torque Capacity • Verify Ceramic Compatibility With Temperature Levels
Hot-Gas Driven Cryogenic Tests	• Turbine Driven With Oxygen-Rich Hot Gas • Pump Tested in Lox • Testing at MSFC	• Verify Ceramic Turbopump Compatibility With High-Thermal Gradients • Demonstrate Ceramic Turbopump Under Simulated Engine Conditions

accommodate thermal-expansion mismatch.

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Industry Involvement: Allied Signal Aerospace Equipment Systems and Allied Signal Ceramic Components, Torrance, California; Allied Signal Research and Technology, Morristown, Nevada; Lockheed Martin Manned Space Systems, New Orleans, Louisiana